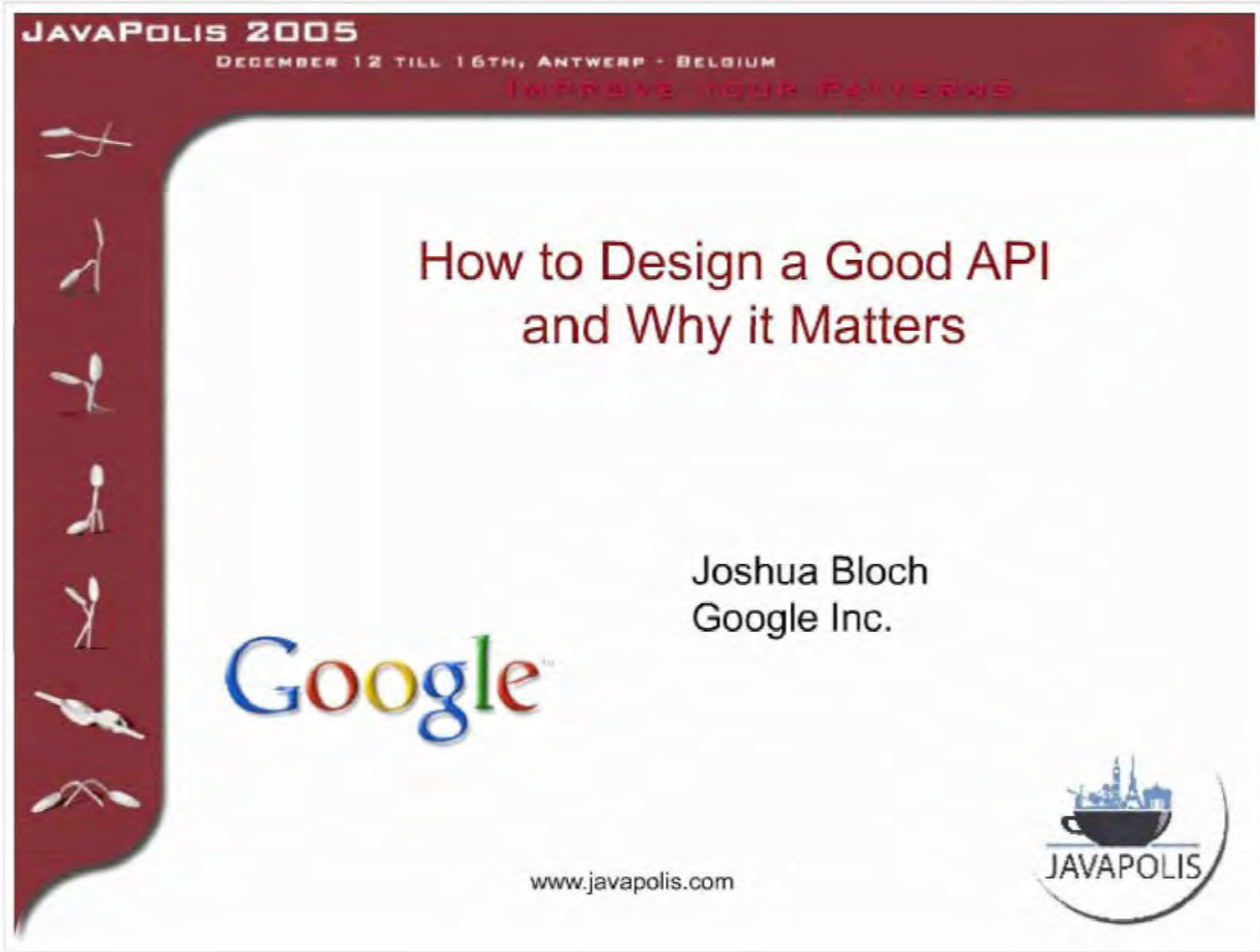
TRIAL EXHIBIT 624



Why is API Design Important?

- APIs can be among a company's greatest assets
  - Customers invest heavily: buying, writing, learning
  - Cost to stop using an API can be prohibitive
  - Successful public APIs capture customers
- Can also be among company's greatest liabilities
  - Bad APIs result in unending stream of support calls
- Public APIs are forever - one chance to get it right

Why is API Design Important to *You*?

- If you program, you are an API designer
  - Good code is modular–each module has an API
- Useful modules tend to get reused
  - Once module has users, can't change API at will
  - Good reusable modules are corporate assets
- Thinking in terms of APIs improves code quality

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Characteristics of a Good API

- Easy to learn
- Easy to use, even without documentation
- Hard to misuse
- Easy to read and maintain code that uses it
- Sufficiently powerful to satisfy requirements
- Easy to extend
- Appropriate to audience

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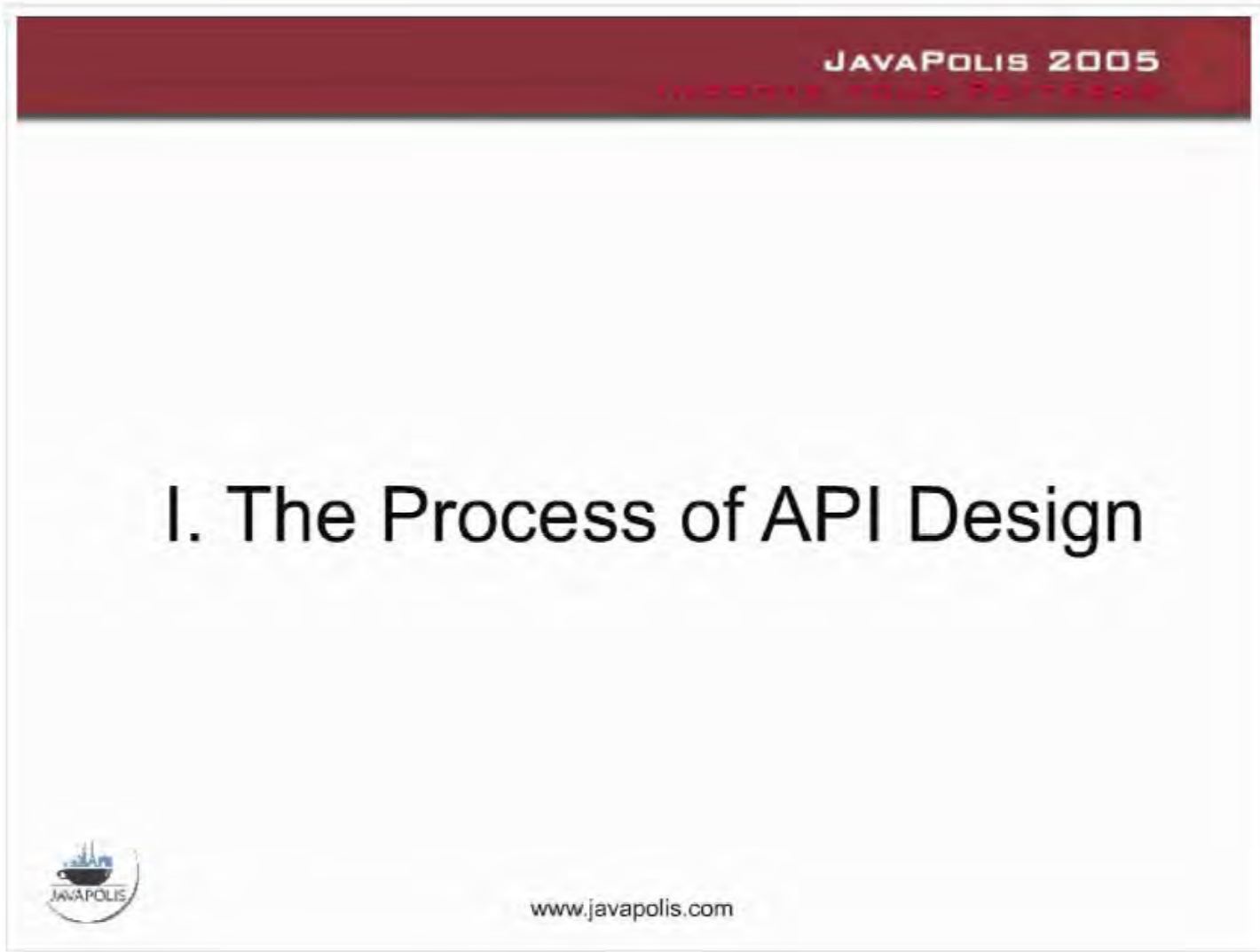
Outline

I. The Process of API Design
II. General Principles
III. Class Design
IV. Method Design
V. Exception Design
VI. Refactoring API Designs



Gather Requirements–with a Healthy Degree of Skepticism

- Often you'll get proposed solutions instead
  - Better solutions may exist
- Your job is to extract true requirements
  - Should take the form of ***use-cases***
- Can be easier and more rewarding to build something more general

Good

Start with Short Spec–1 Page is Ideal

- At this stage, agility trumps completeness
- Bounce spec off as many people as possible
  - Listen to their input and take it seriously
- If you keep the spec short, it's easy to modify
- Flesh it out as you gain confidence
  - This necessarily involves coding

Write to Your API Early and Often

- Start *before* you've implemented the API
  - Saves you doing implementation you'll throw away
- Start *before* you've even specified it properly
  - Saves you from writing specs you'll throw away
- Continue writing to API as you flesh it out
  - Prevents nasty surprises
  - **Code lives on as examples, unit tests**

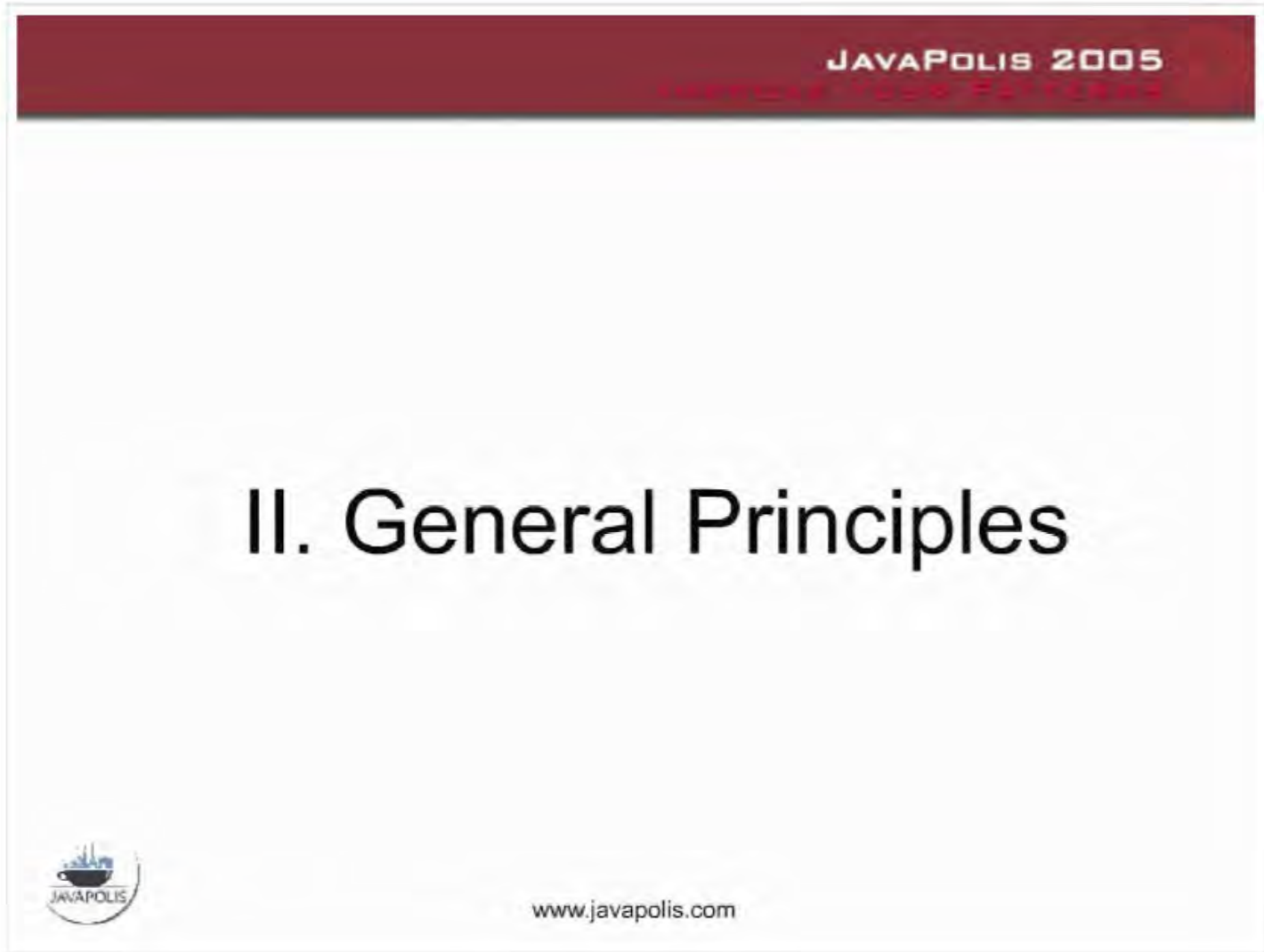
Writing to SPI is Even More Important

- Service Provider Interface (SPI)
  - Plug-in interface enabling multiple implementations
  - Example: Java Cryptography Extension (JCE)
- Write multiple plug-ins before release
  - If one, it probably won't support another
  - If two, it will support more with difficulty
  - If three, it will work fine
- Will Tracz calls this "The Rule of Threes"
  (*Confessions of a Used Program Salesman*, Addison-Wesley, 1995)

Bad

Maintain Realistic Expectations

- Most API designs are over-constrained
  - You won't be able to please everyone
  - Aim to displease everyone equally
- Expect to make mistakes
  - A few years of real-world use will flush them out
  - Expect to evolve API



API Should Do One Thing and Do it Well

- Functionality should be easy to explain
  - If it's hard to name, that's generally a bad sign
  - Good names drive development
  - Be amenable to splitting and merging modules

API Should Be As Small As Possible But No Smaller

- API should satisfy its requirements
- **When in doubt leave it out**
  - Functionality, classes, methods, parameters, etc.
  - **You can always add, but you can never remove**
- *Conceptual weight* more important than bulk
- Look for a good *power-to-weight ratio*

Implementation Should Not Impact API

- Implementation details
  - Confuse users
  - Inhibit freedom to change implementation
- Be aware of what is an implementation detail
  - Do not overspecify the behavior of methods
  - For example: do not specify hash functions
  - All tuning parameters are suspect
- Don't let implementation details "leak" into API
  - On-disk and on-the-wire formats, exceptions

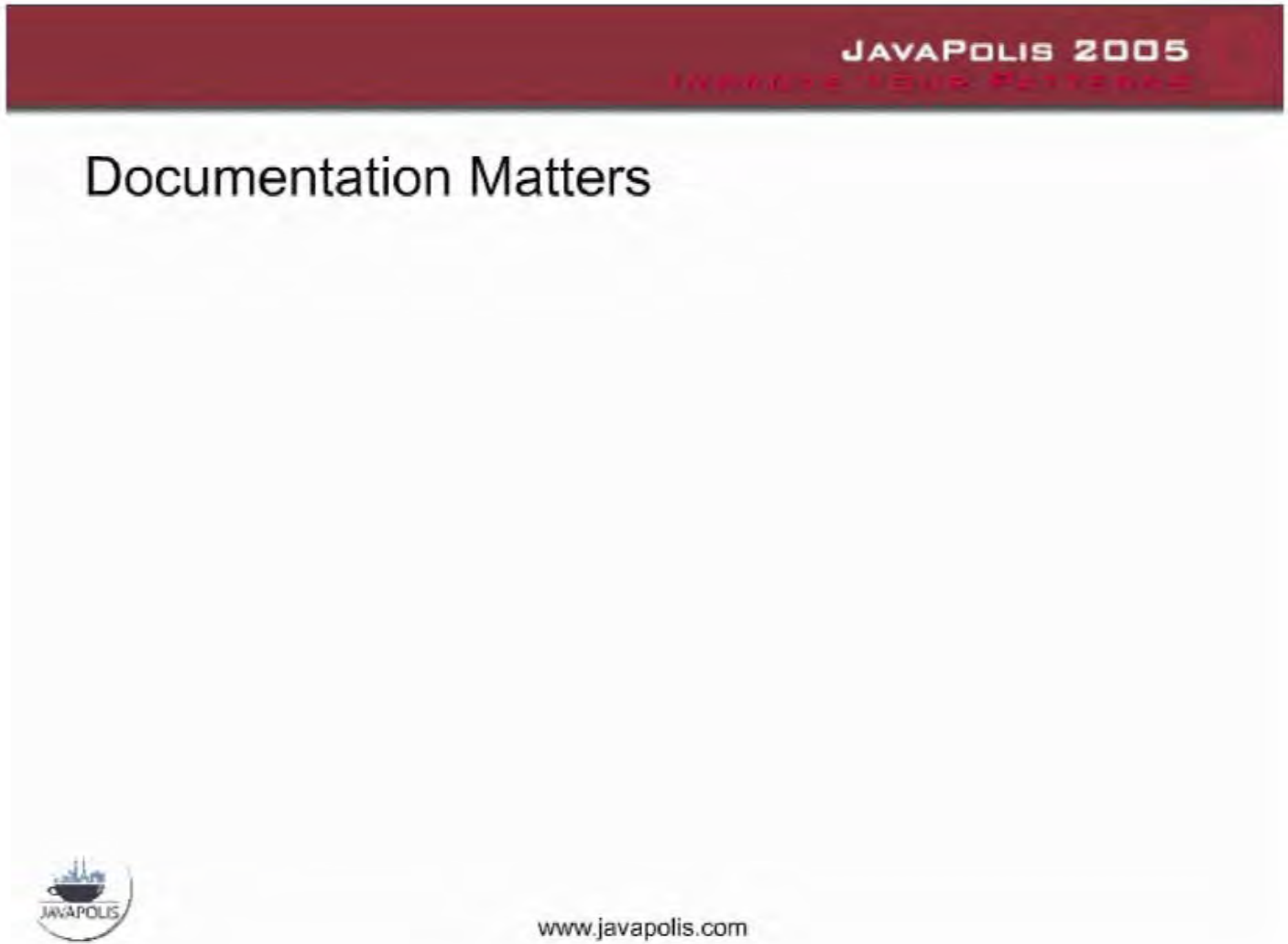
Minimize Accessibility of Everything

- Make classes and members as private as possible
- Public classes should have no public fields (with the exception of constants)
- This maximizes **information hiding**
- Allows modules to be used, understood, built, tested, and debugged independently

Names Matter–API is a Little Language

- Names Should Be Largely Self-Explanatory
  - Avoid cryptic abbreviations
- Be consistent–same word means same thing
  - Throughout API, (Across APIs on the platform)
- Be regular–strive for symmetry
- Code should read like prose

```
if (car.speed() > 2 * SPEED_LIMIT)
   generateAlert("Watch out for cops!");
```



Document Religiously

- Document **every** class, interface, method, constructor, parameter, and exception
  - Class: what an instance represents
  - Method: contract between method and its client
    - Preconditions, postconditions, side-effects
  - Parameter: indicate units, form, ownership
- Document state space very carefully

Consider Performance Consequences of API Design Decisions

- Bad decisions can limit performance
  - Making type mutable
  - Providing constructor instead of static factory
  - Using implementation type instead of interface
- Do not warp API to gain performance
  - Underlying performance issue will get fixed, but headaches will be with you forever
  - Good design usually coincides with good performance

Effects of API Design Decisions on Performance are Real and Permanent

- `Component.getSize()` returns `Dimension`
- `Dimension` is mutable
- Each `getSize` call must allocate `Dimension`
- Causes *millions* of needless object allocations
- Alternative added in 1.2; old client code still slow

API Must Coexist Peacefully with Platform

- Do what is customary
  - Obey standard naming conventions
  - Avoid obsolete parameter and return types
  - Mimic patterns in core APIs and language
- Take advantage of API-friendly features
  - Generics, varargs, enums, default arguments
- Know and avoid API traps and pitfalls
  - Finalizers, public static final arrays
- Don't Transliterate APIs

Minimize Mutability

- Classes should be immutable unless there's a good reason to do otherwise
  - Advantages: simple, thread-safe, reusable
  - Disadvantage: separate object for each value
- If mutable, keep state-space small, well-defined
  - Make clear when it's legal to call which method

Bad: `Date`, `Calendar`

Good: `TimerTask`

Subclass Only Where It Makes Sense

- Subclassing implies substitutability (Liskov)
  - Subclass only when is-a relationship exists
  - Otherwise, use composition
- Public classes should not subclass other public classes for ease of implementation

Bad: `Properties extends Hashtable`
`Stack extends Vector`

Good: `Set extends Collection`

Design and Document for Inheritance or Else Prohibit it

- Inheritance violates encapsulation (Snyder, '86)
  - Subclass sensitive to implementation details of superclass
- If you allow subclassing, document *self-use*
  - How do methods use one another?
- Conservative policy: all concrete classes final
- Bad: Many concrete classes in J2SE libraries
- Good: `AbstractSet`, `AbstractMap`

Don't Make the Client Do Anything the Module Could Do

- Reduce need for boilerplate code
  - Generally done via cut-and-paste
  - Ugly, annoying, and error-prone

```
import org.w3c.dom.*;
import java.io.*;
import javax.xml.transform.*;
import javax.xml.transform.dom.*;
import javax.xml.transform.stream.*;

// DOM code to write an XML document to a specified output stream.
static final void writeDoc(Document doc, OutputStream out)throws IOException{
  try {
    Transformer t = TransformerFactory.newInstance().newTransformer();
    t.setOutputProperty(OutputKeys.DOCTYPE_SYSTEM,
  doc.getDoctype().getSystemId());
    t.transform(new DOMSource(doc), new StreamResult(out));
  } catch(TransformerException e) {
    throw new AssertionError(e);  // Can't happen!
  }
}
```

Don't Violate *Principle of Least Astonishment*

- User of API should not be surprised by behavior
  - It's worth extra implementation effort
  - It's even worth reduced performance

```
public class Thread implements Runnable {
  // Tests whether current thread has been interrupted.
  // Clears the interrupted status of current thread.
  public static boolean interrupted();
}
```

Fail Fast–Report Errors as Soon as Possible After They Occur

- Compile time is best - static typing, generics
- At runtime, first bad method invocation is best
  - Method should be failure-atomic

```
// A Properties instance maps strings to strings
public class Properties extends Hashtable {
   public Object put(Object key, Object value);

   // Throws ClassCastException if this properties
   // contains any keys or values that are not strings
   public void save(OutputStream out, String comments);
}
```

Provide Programmatic Access to All Data Available in String Form

- Otherwise, clients will parse strings
  - Painful for clients
  - Worse, turns string format into de facto API

```
public class Throwable {
  public void printStackTrace(PrintStream s);
  public StackTraceElement[] getStackTrace(); // Since 1.4
}
public final class StackTraceElement {
  public String getFileName();
  public int getLineNumber();
  public String getClassName();
  public String getMethodName();
  public boolean isNativeMethod();
}
```

Overload With Care

- Avoid *ambiguous overloadings*
  - Multiple overloadings applicable to same actuals
  - Conservative: no two with same number of args
- Just because you can doesn't mean you should
  - Often better to use a different name
- If you must provide ambiguous overloadings, ensure same behavior for same arguments

```
public TreeSet(Collection c); // Ignores order
public TreeSet(SortedSet s);  // Respects order
```

Use Appropriate Parameter and Return Types

- Favor interface types over classes for input
  - Provides flexibility, performance
- Use most specific possible input parameter type
  - Moves error from runtime to compile time
- Don't use string if a better type exists
  - Strings are cumbersome, error-prone, and slow
- Don't use floating point for monetary values
  - Binary floating point causes inexact results!
- Use `double` (64 bits) rather than `float` (32 bits)
  - Precision loss is real, performance loss negligible

Use Consistent Parameter Ordering Across Methods

- Especially important if parameter types identical

```
#include <string.h>
char *strcpy (char *dest, char *src);
void bcopy   (void *src,  void *dst, int n);
```

`java.util.Collections` – first parameter always collection to be modified or queried

`java.util.concurrent` – time always specified as `long delay, TimeUnit unit`

Avoid Long Parameter Lists

- Three or fewer parameters is ideal
  - More and users will have to refer to docs
- Long lists of identically typed params harmful
  - Programmers transpose parameters by mistake
  - Programs still compile, run, but misbehave!
- Two techniques for shortening parameter lists
  - Break up method
  - Create helper class to hold parameters

```
// Eleven parameters including four consecutive ints
HWND CreateWindow(LPCTSTR lpClassName, LPCTSTR lpWindowName,
      DWORD dwStyle, int x, int y, int nWidth, int nHeight,
      HWND hWndParent, HMENU hMenu, HINSTANCE hInstance,
      LPVOID lpParam);
```

Avoid Return Values that Demand Exceptional Processing

- Return zero-length array or empty collection, not **null**

```
package java.awt.image;
public interface BufferedImageOp {
  // Returns the rendering hints for this operation,
  // or null if no hints have been set.
  public RenderingHints getRenderingHints();
}
```

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V. Exception Design

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Throw Exceptions to Indicate Exceptional Conditions

- Don't force client to use exceptions for control flow

```
private byte[] a = new byte[BUF_SIZE];
void processBuffer (ByteBuffer buf) {
  try {
    while (true) {
      buf.get(a);
      processBytes(tmp, BUF_SIZE);
    }
  } catch (BufferUnderflowException e) {
    int remaining = buf.remaining();
    buf.get(a, 0, remaining);
    processBytes(bufArray, remaining);
  }
}
```

- Conversely, don't fail silently

```
ThreadGroup.enumerate(Thread[] list)
```

Favor Unchecked Exceptions

- Checked – client must take recovery action
- Unchecked – programming error
- Overuse of checked exceptions causes boilerplate

```
try {
    Foo f = (Foo) super.clone();
    ....
} catch (CloneNotSupportedException e) {
    // This can't happen, since we're Cloneable
    throw new AssertionError();
}
```

Include Failure-Capture Information in Exceptions

- Allows diagnosis and repair or recovery
- For unchecked exceptions, message suffices
- For checked exceptions, provide accessors

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VI. Refactoring API Designs

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1. Sublist Operations in Vector

```
public class Vector {
    public int indexOf(Object elem, int index);
    public int lastIndexOf(Object elem, int index);
    ...
}
```

- Not very powerful - supports only search
- Hard too use without documentation

Sublist Operations Refactored

```
public interface List {
    List subList(int fromIndex, int toIndex);
    ...
}
```

- Extremely powerful - supports *all* operations
- Use of interface reduces conceptual weight
  - High power-to-weight ratio
- Easy to use without documentation

2. Thread-Local Variables

```
// Broken - inappropriate use of String as capability.
// Keys constitute a shared global namespace.
public class ThreadLocal {
    private ThreadLocal() { } // Non-instantiable

    // Sets current thread's value for named variable.
    public static void set(String key, Object value);

    // Returns current thread's value for named variable.
    public static Object get(String key);
}
```

Thread-Local Variables Refactored (1)

```
public class ThreadLocal {
    private ThreadLocal() { } // Noninstantiable

    public static class Key { Key() { } }

    // Generates a unique, unforgeable key
    public static Key getKey() { return new Key(); }

    public static void set(Key key, Object value);
    public static Object get(Key key);
}
```

- Works, but requires boilerplate code to use

```
static ThreadLocal.Key serialNumberKey = ThreadLocal.getKey();
ThreadLocal.set(serialNumberKey, nextSerialNumber());
System.out.println(ThreadLocal.get(serialNumberKey));
```

Thread-Local Variables Refactored (2)

```
public class ThreadLocal {
    public ThreadLocal() { }
    public void set(Object value);
    public Object get();
}
```

- Removes clutter from API and client code

```
static ThreadLocal serialNumber = new ThreadLocal();
serialNumber.set(nextSerialNumber());
System.out.println(serialNumber.get());
```

Conclusion

- API design is a noble and rewarding craft
  - Improves the lot of programmers, end-users, companies
- This talk covered some heuristics of the craft
  - Don't adhere to them slavishly, but...
  - Don't violate them without good reason
- API design is tough
  - Not a solitary activity
  - Perfection is unachievable, but try anyway